Combining active and passive solar concepts in building design:

Case study of Prabha Bhavan, MNIT Jaipur, India

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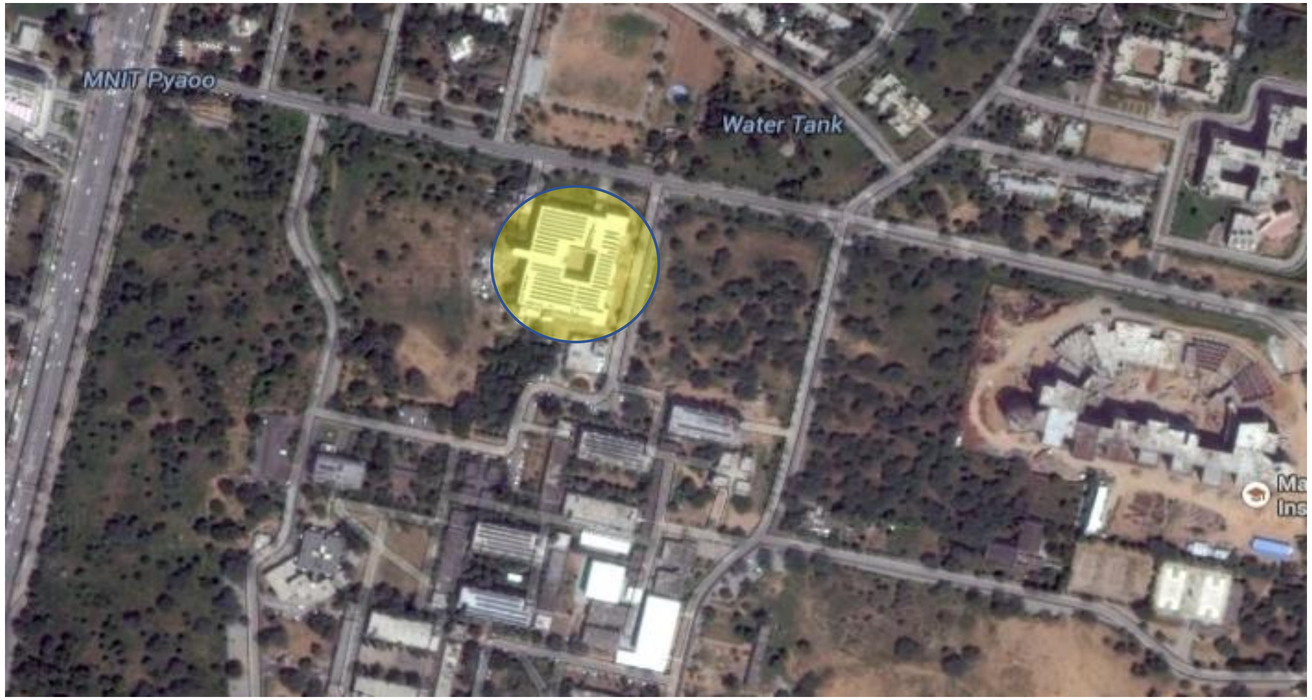
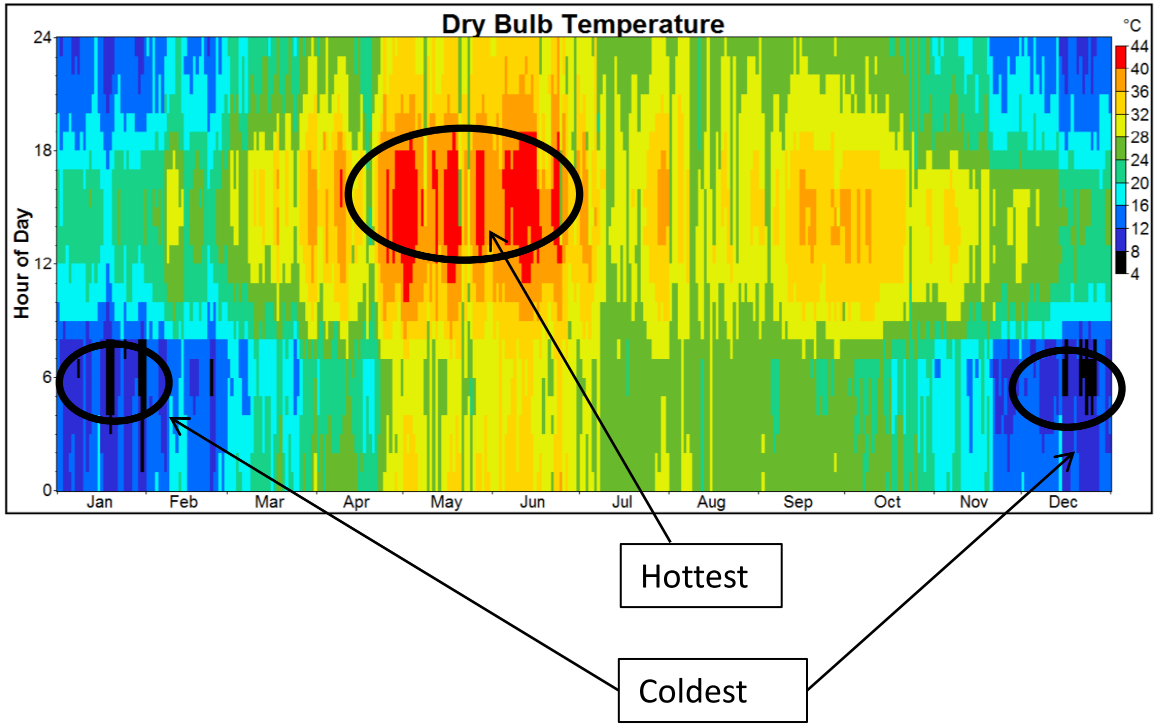
Building Location

India-Rajasthan-Jaipur (26.49° N, 75.48° E)

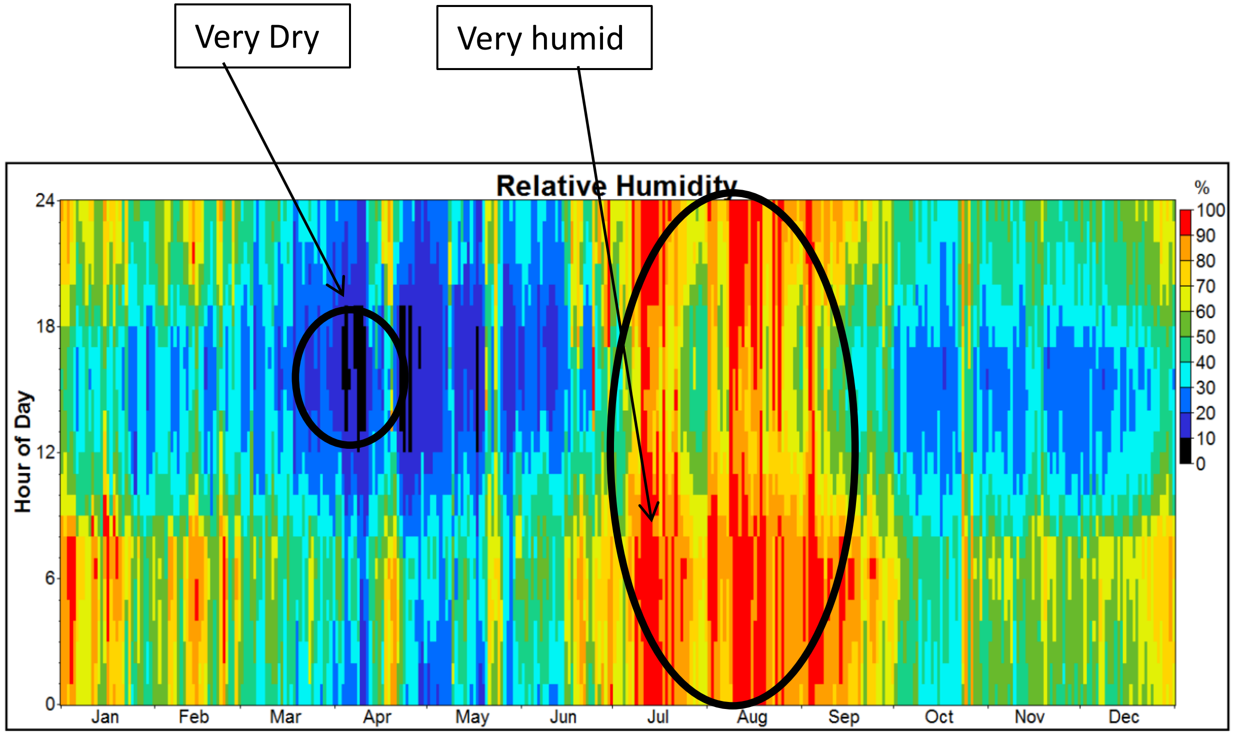


Variation in outdoor temperature and humidity

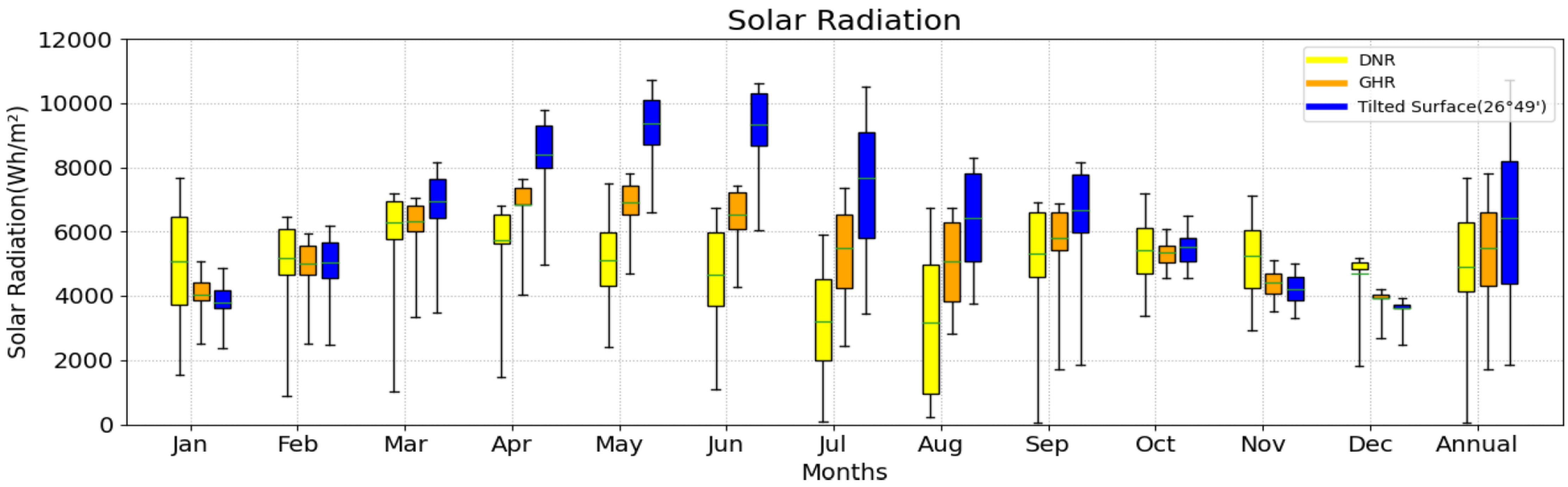
Dry Bulb Temperature (°C)



Source: Indian Weather Data 2017, ISHRAE



Solar Energy Availability



Prabha Bhavan Building

Project Description

❖ **Building usage**	**: Office cum computer centre**
❖ **Building operation**	**: Mon-Fri (8:00 am to 8:00 pm)** *(except computer labs)*
❖ **Total floors**	**: Three (G+2)**
❖ **Carpet area**	**: 11306 m^2**
❖ **Conditioned area**	**: 9959 m^2**
❖ **Unconditioned area**	**: 1347 m^2**
❖ **WWR**	**: 27 %**

Features on front side (East)

- Self shading entry foyer
- Vertical fins
- Recessed side entrances
- Thermal mass

Features on south side

- Maximum solar load is from southern side
- Corridor on south side to protect direct solar load
- Located buffer spaces (non regularly occupied spaces) in south

Extent of self shading on façade in summer noon

Features on West Side

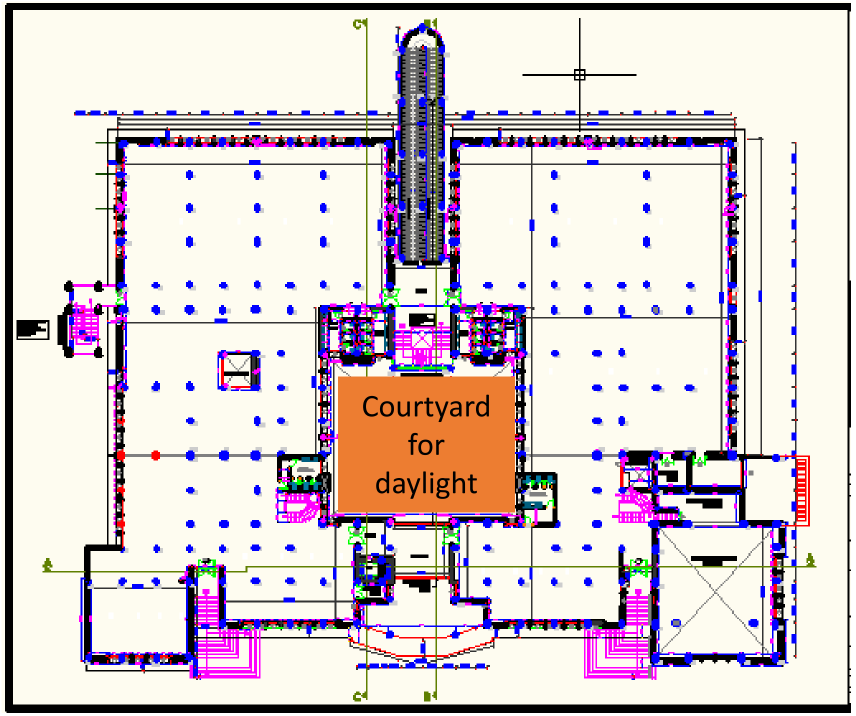
- Vertical fins to block low west sun beyond west in evening
- Projected ramp structure to partially shade west facade

Features on North Side

- Vertical fins to block low north-western and north-eastern sun
- Reduces load in morning and evening during summer

Courtyard design

- Primarily for daylight (energy saving and wellness)
- Facilitate mixed mode operation during moderate months



Construction and Other Systems Used

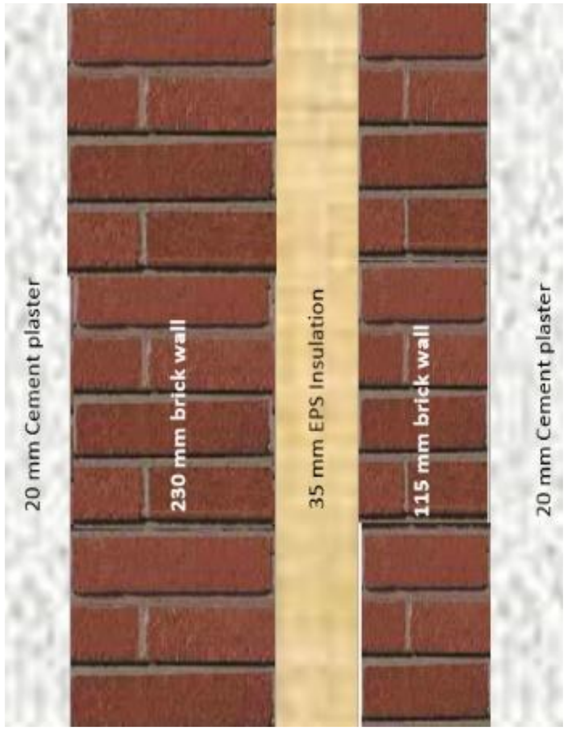
Features of Envelope:

Roof:	XPS insulation and tiles on terrace
Wall:	1.5” Sandwiched insulation (except ground floor)
Glazing:	DGU, with Low-E coating on surface-2, UPVC frame
Shading:	Vertical fins, overhangs

Technologies deployed

HVAC:	Through VRF units with heat pump
Heat recovery wheel	In two auditoriums
Duct insulation:	PU foam
Lighting:	Dimmable LEDs, with daylight integration
Rooftop Solar PV:	150 kWp

Measures for Wall and Roof



Basis of decisions:

- Under deck insulation used due to water proofing issue
- Decision about insulation on wall and roof was taken on the basis of payback analysis, **including cost of avoided Tonnage**
- Roof U-value is lower than code due to additional layer of inverted earth pots used

Sample Decision Making Process

	Normal construction	1" roof+1" wall	1.5" roof + 1.5" wall	2" roof+ 2" wall
Roof insulation (inches)		1.00	1.50	2.00
Wall insulation (inches)		1.00	1.50	2.00
Energy consumption kWh/yr	1562100	1444400	1442200	1429800
Reduction in TR	0.00	77	80	82
Saving in Rs/yr @8/- per kWh		941600	959200	1058400
Cost of roof insulation (Rs.)		2400000	3600000	4800000
Cost of wall insulation (Rs.)		4500000	6750000	9000000
Total cost of insulation (Rs.)		6900000	10350000	13800000
Payback (yrs)		**7.3**	**10.8**	**13.0**
Avoided cost due to reduced TR		3850000	4000000	4100000
Revised extra investment		3050000	6350000	9700000
Revised payback		**3.2**	**6.6**	**9.2**

Glazing selection

Glass properties	Standard case	Proposed case
U- value (W/m²-ºC)	3.3	2.2
SHGC *(unadjusted)*	0.25	0.28 (through parametric analysis)

Basis of decisions:

- ❖ Low SHGC High VLT (0.39) glass chosen through **daylight simulation**
- ❖ SHGC of glass kept slightly higher than prescriptive approach due to presence of shading by fins
- ❖ Higher value of SHGC ***(unadjusted)*** was useful in having high VLT for daylight saving

Special care for window and lighting

- The decision of glazing and lighting type was taken ***together*** with decision of using lighting control for ensuring ***compatibility and benefits*** of glazing and lighting

- This was necessary for utilizing properties of window for minimizing lighting energy consumption

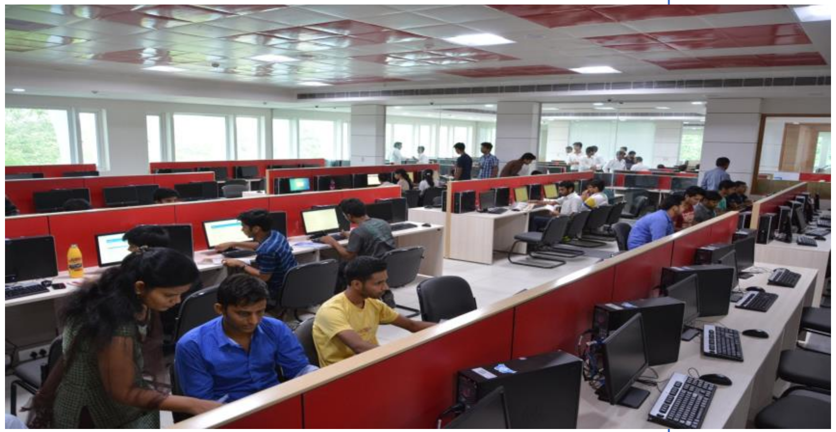
- 30% window area was kept operable to open this building in mixed mode

Lighting Design

ECBC LPD : 1 W/ft^2 (For office activity)

- LPD at project : 0.43 W/ft^2
- Types of lamps : LED
- Type of ballast : Dimmable for daylight integration

  (square for working area, 6” round for aisles and corridors)
- Type of fixtures: 2X2 square and 6” round down-lighters
- Simulation used for ensuring desired lighting level



Air-conditioning

- **System Type** : Variable Refrigerant Volume (VRF) Systems
- **Units installed** : 54
- **Capacity per unit** : 12 HP
- **Total Capacity**: 648 HP

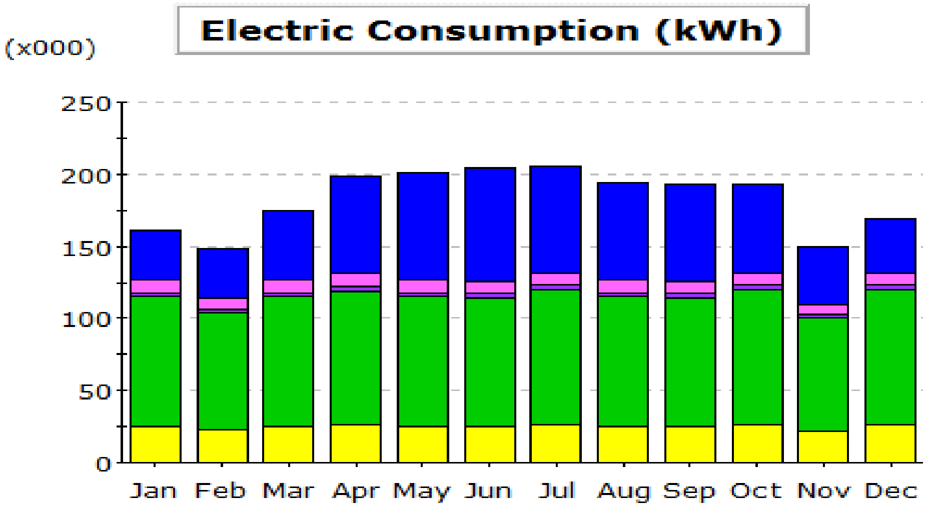
Reason for using VRF systems

- ❖ Limited availability of water was forcing to use air cooled system
- ❖ Building is likely to have large diversity due to vacation of students, exam period, seminars and training programs, including closing of some sections over some periods, besides seasonal diversity
- ❖ Decision about exact usage of building had some uncertainties, modularity was better with VRF systems
- ❖ Lost opportunity to have high solar fraction with use of water cooled chillers

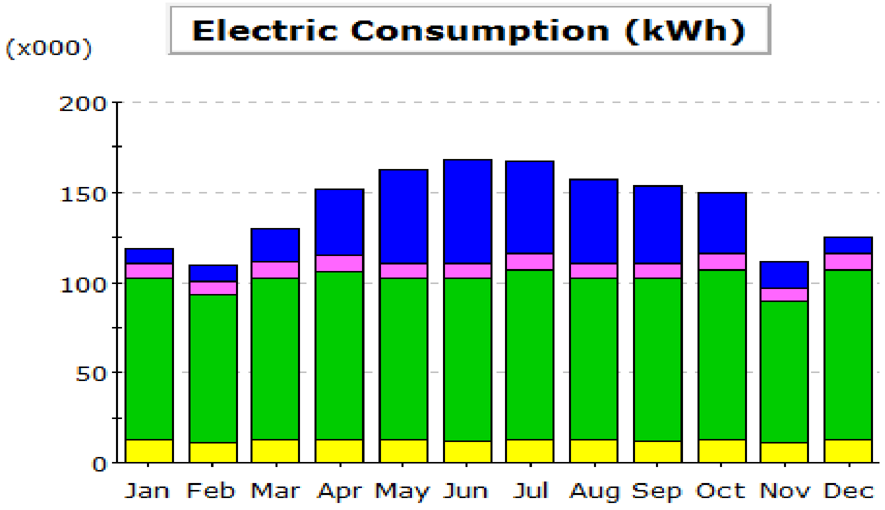
Summary of parameters

Criteria	Standard Case	Design Case
Building Envelope		
Roof [U-value (W/m² ℃)]	0.409	0.35
Wall [U-value (W/m² ℃)]	0.44	0.72
Glazing (SHGC)	0.25	0.28
Glazing [U-value (W/m² ℃)]	3.3	1.9
Glazing (VLT)	0.27	0.39
Air Conditioning		
HVAC	RHFS (COP = 3.05)	VRF (COP = 3.75)
Schedules		
Occupancy (ft²/person)	58	58
Lighting (W/ft²)	1	0.43
EPD (W/ft²)	2.2	2.2

Simulation results: Monthly summary



Standard case



Proposed case

Options considered for rooftop Solar PV Plant

- PV system with all grid export (common in India)
- PV system with battery, no grid export, captive consumption
- PV system with battery and grid export (costliest)

Influencing factors:

- Generation on weekends
- Power supply during grid outage

Active Solar: SPV Plant

- ❖ Installed PV Capacity : 150 kW_p (3X50)
- ❖ Cell type: Crystalline Si
- ❖ Number of PV modules : 630
- ❖ Inverter Capacity : 50kVA*3/inverter
- ❖ Modules in a string : 15 (Nos)
- ❖ Strings in parallel : 14 (Nos)
- ❖ Power export to local grid enabled
- ❖ Building level battery storage (4 hrs backup, except AC load)

Summary - Energy Savings

	Standard case	Proposed case	Savings %
Energy consumption (MWh)	2057	1449	30%
EPI (kWh/m2/yr)	182	128	30%
Annual peak demand (kW)	1020	801	22%
PV electricity generation (MWh)		307	21.2%

Comparison with normal design

- No shading: 5%
- No special zoning of blocking south zones with facilities: 12%
- No projection on western façade: 4%
- No daylight integration: 2%
- Total increase: 23%
- Window sizing to 40%: 15%
- Total savings with window sizing: 38%

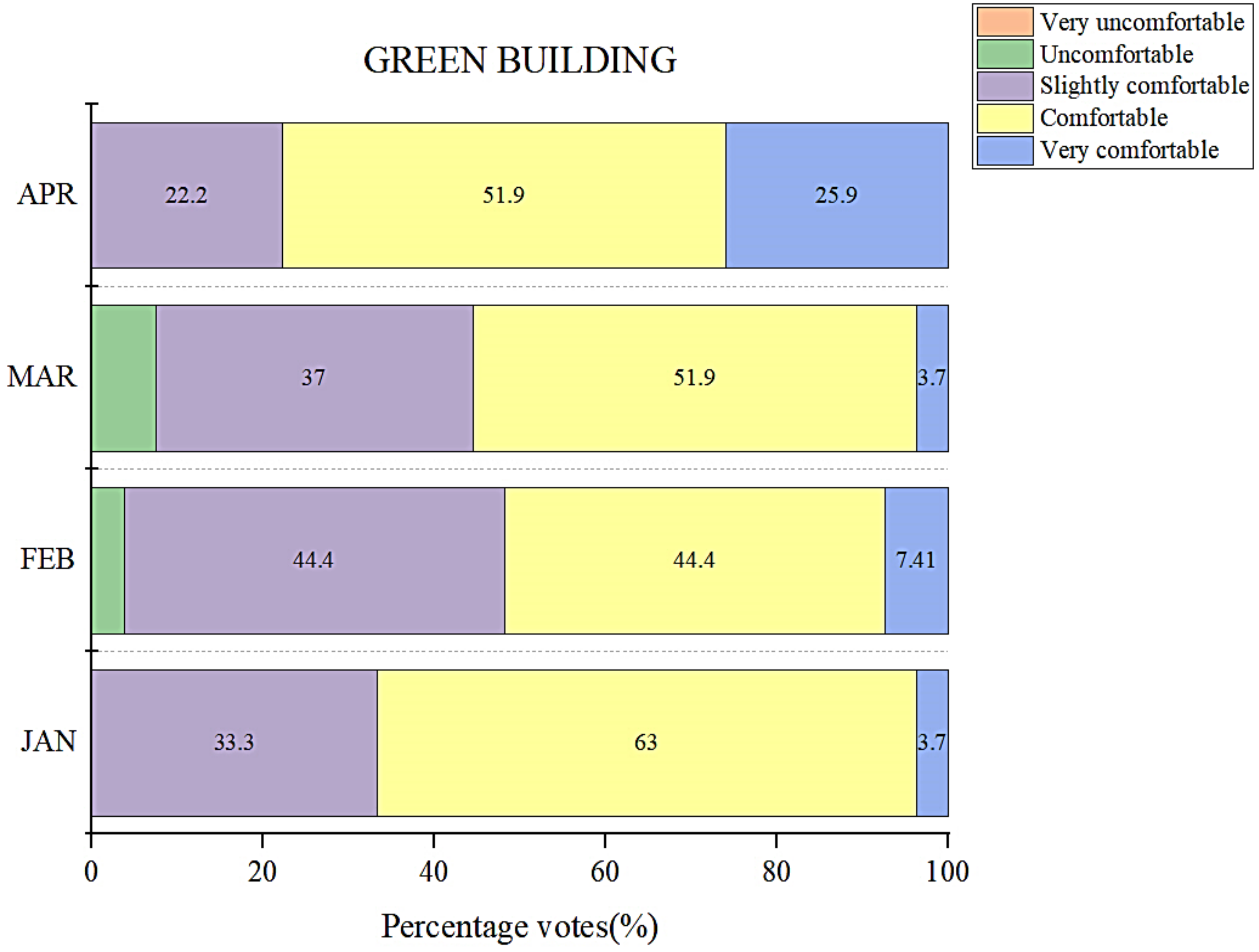
Issues faced during operation

- Soiling of modules
- Rodent attack on wiring
- Hail damaged PV modules
- Inverter burn out due to dead batteries (maintenance issue)
- String mismatch due to replaced modules impacting generation

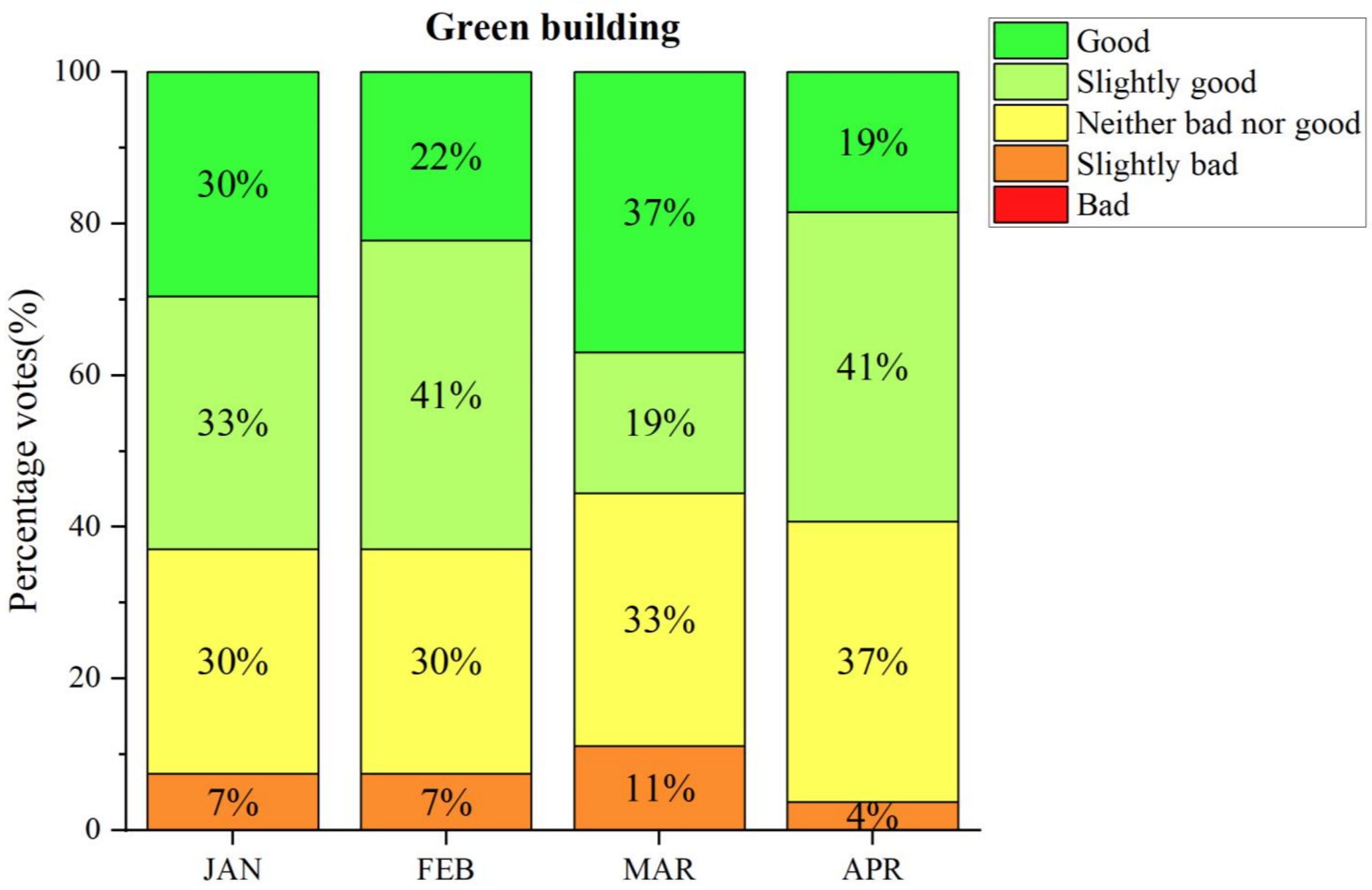
Recent retrofitting:

- Removed batteries,
- Re-configured modules 10kVA new string inverters

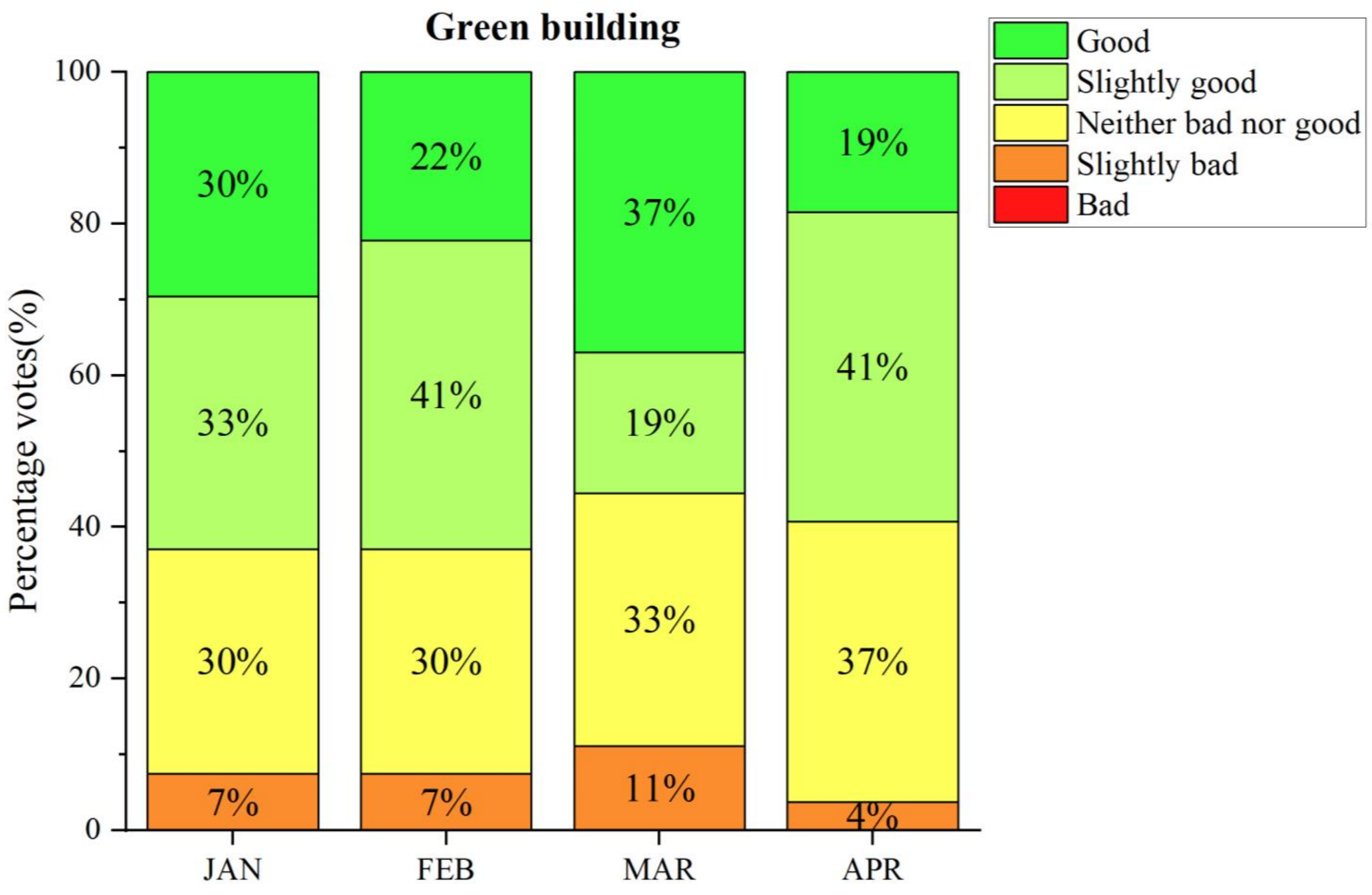
Occupant feedback for thermal confort



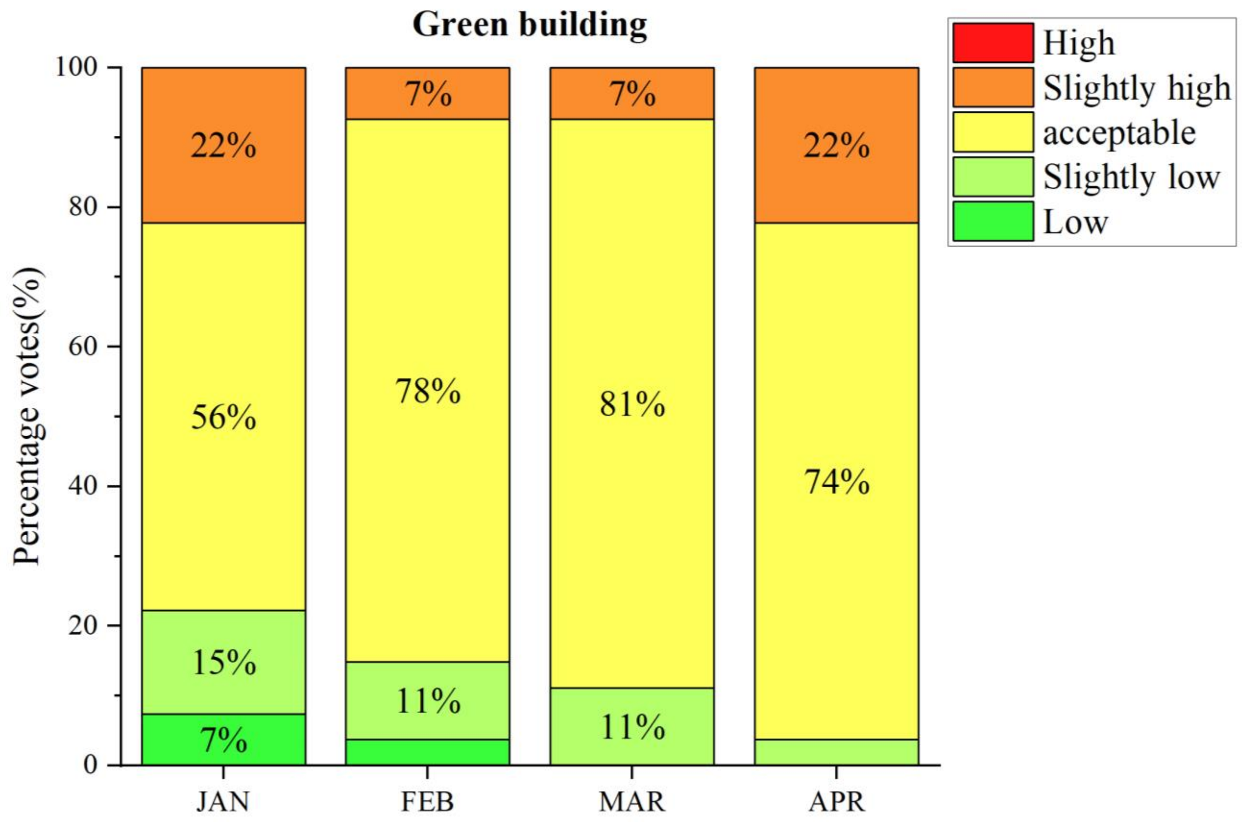
Occupant feedback for air quality



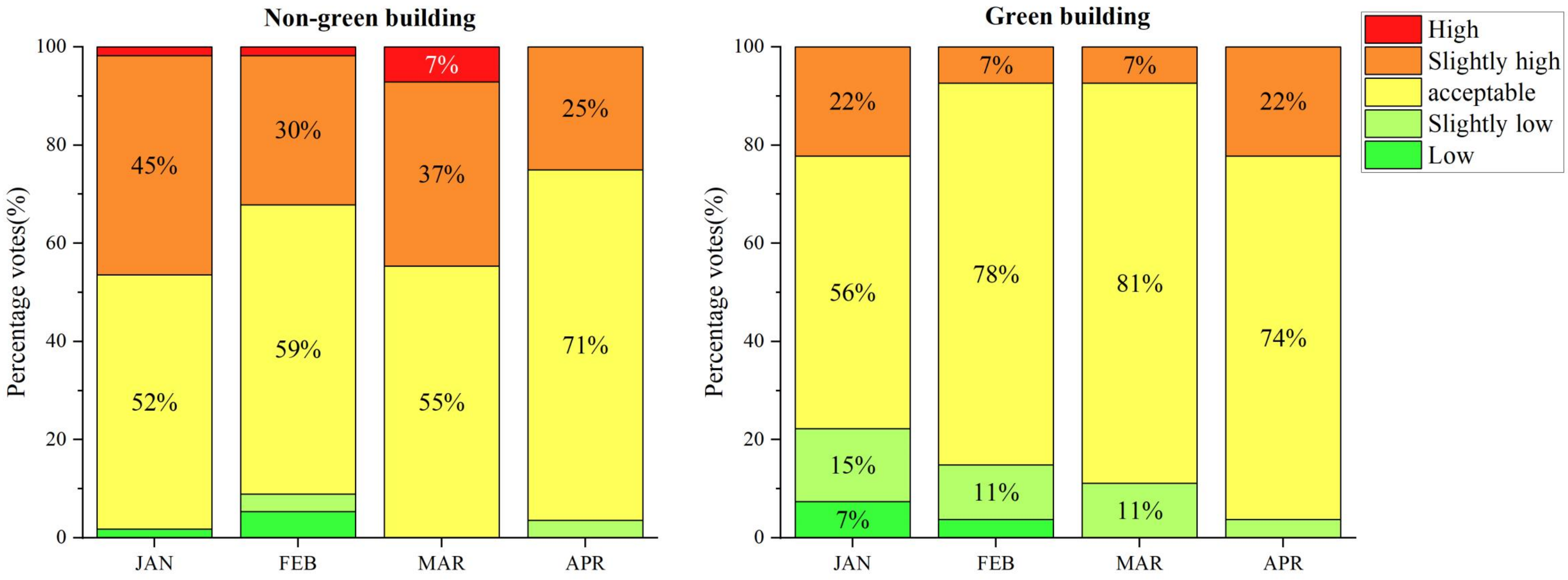
Occupant feedback for air quality



Occupant feedback for illumination



Overall noise



Graph 10 : Monthly variation of noise in GB and NGB

- On average, 37% and 14.2% occupants felt that noise inside the building was “Slightly high” and “high” in NGB and GB respectively.
- This clearly shows that acoustic comfort in NGB is poor as compared to GB.

Summary

- Share of active solar in Prabha Bhavan building is 21% of energy consumption
- Passive solar design concepts put together save/avoid 38% of energy
- Is it better or inferior than some other building having 30-40% solar and no solar passive design?
- Can the building be treated as 21+38=59% (say 60%) solar?

Thanks!!

Questions??